AD-A158 532 INVESTIGATION OF THE MULTIAXIAL PROPERTIES OF SNOW AT HIGH RATES OF DEFOR..(U) MONTANA STATE UNIV BOZEMAN DEPT OF CIVIL ENGINEERING AND ENGI.. R L BROWN 1/1

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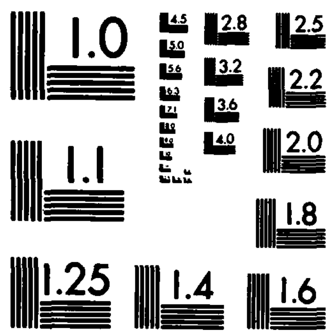

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER ARO 18730.3-GS	2. GOVT ACCESSION NO. N/A	3. RECIPIENT'S CATALOG NUMBER N/A
4. TITLE (and Subtitle) Investigation of the Multiaxial Properties of Snow at High Rates of Deformation		5. TYPE OF REPORT & PERIOD COVERED Final, 1982-1985
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Robert L. Brown		8. CONTRACT OR GRANT NUMBER(s) DAAG29-82-K-0127
9. PERFORMING ORGANIZATION NAME AND ADDRESS CE/EM Department, Montana State University, Bozeman, MT 59717		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS U. S. Army Research Office, Post Office Box 12211, Research Triangle Park, NC 27709		12. REPORT DATE Aug. 1, 1985
		13. NUMBER OF PAGES 7
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) AD-A158 532		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

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17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

NA

18. SUPPLEMENTARY NOTES

The view, opinions, and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other documentation.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Constitutive equations
Snow

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A constitutive equation was developed to describe the behavior of snow subjected to high rate multiaxial deformations. This constitutive law is therefore usable in the analysis of stress waves in snow, vehicle mobility in snow, and terminal ballistics, as it is capable of describing the response of the material to deformations which occur at high rates and result with large strains. In addition, the constitutive theory is defined in terms of the micro-structural properties of the material, i.e. grain size, (Continued on back)

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bond diameter, pore size, bond length, bond number density, and specific surface area.

A stress wave program was also carried out to provide the data with which to evaluate the constitutive theory and to make any emperical adjustments necessary. This process is still being carried out.

Finally, ~~a very substantial~~ effort was devoted to developing a stereological theory with which to evaluate the microstructure of the material. This effort resulted with the ability to calculate all of the microstructural properties mentioned above, irrespective of grain size and shape distributions.

ARO 18730.3-GS

INVESTIGATION OF THE MULTIAXIAL PROPERTIES OF SNOW AT HIGH RATES OF DEFORMATION

FINAL REPORT

By

R. L. Brown

~~July~~ 1985
1 Aug

US ARMY RESEARCH OFFICE

GRANT NO. DAAG29-82-K-0127

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I. STATEMENT OF PROBLEM STUDIED

The research project described here was concerned with the development of multiaxial constitutive equations for low-to-medium density snow. The constitutive equations were to have the following characteristics:

(1) describe the material behavior in terms of the microstructural properties of the material

(2) represent the material for intermediate and high strain rates, large strains, and multiaxial states of stress.

The constitutive formulation would have to satisfy the requirements of material frame indifference and have a thermodynamic basis in that it would be consistent with the second law of thermodynamics.

The first criterion listed above would require a major development in itself, since measuring important microstructural properties is a difficult problem. A method for (i) determining which microstructural properties (such as grain size, pore size, bond length, bond radius, density, bonds/grain, specific surface area, etc.) are relevant to deformation, (ii) quantitatively measuring these parameters, and (iii) determining how they vary with macroscopically observable variables such as strain and strain rate.

In order to accomplish this, a complete stereological theory had to be formulated. Current stereological formulations, to the author's knowledge, were not adequate for accurately determining these microstructural parameters for porous materials with irregular grain size, shape, and distribution.

Once the stereological analysis was developed, a constitutive theory then had to be considered. During the past thirty to forty years, a number of formulations have been used to describe the behavior of snow.

These formulations have included linear elastic, linear viscoelastic, nonlinear viscoelastic, Newtonian fluid, nonNewtonian fluid, and elastic-plastic models. None of these models can be considered to be truly correct, since snow is neither elastic, viscoelastic, fluid or plastic in behavior. However any of the above formulations can give a good approximation of the material behavior if certain conditions (usually quite restrictive) on the deformations are met.

What was to be attempted in this project was the development of a constitutive equation which would enable one to determine alterations in the microstructure of the material due to loading. This constitutive law would also be more general than preceding formulations and hence could be applied to a broader class of problems. In addition it was anticipated that this formulation would add to current understanding of the important deformation mechanisms. Once the general formulation was finished, it was also intended to consider simplified forms which could be used for special situations.

Finally, some testing was to be done in order to evaluate the above results. A stress wave test program was to be instituted to observe the alteration of the material microstructure due to shockwaves. Also the results would be compared to those predicted by the constitutive theory.

II. SUMMARY OF RESULTS

The research project was divided into three main parts, based on the work effort needed to achieve the project goals. These are: (a) development of a stereological theory for evaluating the microstructure of snow, (b) formulation of a constitutive equation, and (c) a stress wave test program.

The first part of the project required a major development effort, since current stereological theory was not developed to the point where it could be used to make a detailed microstructural analysis of a material with highly irregular grain structure. The ability to measure such properties as mean grain size, pore size, density, bond diameter, neck length and the number of bonds per grain was mandatory. These parameters were to be used in the formulation of a constitutive theory for snow, since they were considered to be the important microstructural properties which determine the mechanical properties of snow. These parameters were to be used in constructing the constitutive theory for snow.

A stereological formulation was developed. This theory allows one to calculate, with the use of a surface section of snow, all of the above mentioned microstructural parameters. These calculations can be made irregardless of the grain size and shape distributions. To the author's knowledge, this represents a new development. It also enables one to avoid using thin sections to analyze the microstructure of snow. Thin section techniques entail a more tedious procedure to acquire the same information.

The second portion of the project was the development of a multiaxial constitutive theory for large, high rate deformation of snow. This theory models the material as a visco-plastic material. The Lagrangian strain rate is determined to be a function of the stress, stress rate, and a state vector which represents the microstructural properties of the material. The history dependence of the material is defined in terms of evolution relations which determine the rate of change of the state variables in terms of the current state variables and the stress state. The state vector has as components the density, grain

size, pore size, bond diameter, neck length, number of bonds per grain, and the surface area per unit volume of the material.

The resulting formulation goes a long way toward defining much more accurately then previously done the relative importance of the various deformation mechanisms which contribute to the overall deformation of a porous material such as snow. However, it is a complicated theory requiring a computer program to use the formulation. The next step in this development would be a program to specialize this formulation to special, restricted classes of deformation in which only one or two of the various mechanisms are predominant. In this way valid simplified equations can be generated.

The final stage of the project was a stress wave testing program. This was carried out during the 1984-85 winter. This program was run in order to provide means of evaluating the constitutive equation and to learn more about stress wave propagation in snow. The microstructure of the material was evaluated both before and after the stress wave shots. Pressure profiles, attenuation rates and air wave profiles were all measured in the tests. Unfortunately, only a limited number of tests were completed before two of the three pressure transducers were destroyed. However, the acquired data does appear to be sufficient to evaluate the constitutive formulation. This evaluation process is still in progress and should be finished sometime in October.

Finally, one project was added to the objectives of the proposal. This involved the development of a microprocessor-based penetrometer to quickly and accurately obtain a permanent record of the strength profile of snowcover. This instrument was of considerable use in finding uniform snow layers in which to conduct the stress wave experiments. However,

the instrument has also sparked much interest among people who are involved in avalanche hazard forecasting, since it provides, in five minutes, more information than the Ram penetrometer provides in an hour. The Ram penetrometer is currently the standard instrument used in avalanche hazard evaluation.

III. PUBLICATIONS AND CONFERENCE PRESENTATIONS

(1) "Problems associated with shockwave propagation in geologic materials with snow as an example", Journal of Rheology, Vol. 28, No. 6 (1985).

(2) "A comparison of unsteady wave propagation for various snowpack properties", Annals of Glaciology, Vol. 4, 1983.

(3) "A numerical evaluation of footing settlement into uniform snowcover", Cold Regions Science and Technology (submitted).

(4) "The effect of freewater content on the effectiveness of explosives in snow", International Snow Science Workshop, Aspen, CO, Oct. 1984.

(5) "A digital thermo-resistograph for evaluating material properties of snowcover", International Snow Science Workshop, Aspen, CO., Oct. 1984.

(6) "Stress waves in natural snowcover", Workshop on Snow Property Measurement, Chateau Lake Louise, Alberta, April, 1985.

(7) "The granular structure of snow: an internal state variable approach", Journal of Glaciology (submitted).

(8) "Studies of shockwaves in wet and dry snow", Proceedings of the Annual Meeting of the Japan Society of Snow and Ice, Tokyo, Japan, (1984).

(9) "A new instrument for measuring the strength of snowcover", Journal of Glaciology (submitted).

(10) "A new constitutive theory for snow based on a microstructural approach", International Journal of Engineering Science, (in preparation).

(11) "The effect of crack formation on attenuation rates in snow", Journal of Glaciology, (in preparation).

IV. PARTICIPATING PERSONNEL AND DEGREES CONFERRED

(1) Robert L. Brown, Professor

(2) Andrew Hansen, Graduate Student (Ph.D. degree to be completed in Dec.).

(3) Timothy Dowd, Graduate Student (M.S. degree granted in June 1984).

(4) Renee M. Lang, Graduate student (M.S. degree granted in June 1985).

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